ANALYSIS OF SPECTRUM SENSING SCHEMES THROUGH TMS320c6713DSK FOR COGNITIVE RADIO NETWORKS

A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of B.Tech & M.Tech Dual

in

Electrical Engineering

(Specialization : Electronics system and Communication)

By:

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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(2010-2015)

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CERTIFICATE

This is to certify that the thesis entitled "***Analysis of Spectrum Sensing schemes through TMS320c6713DSK for Cognitive Radio Networks***" being submitted by ***Jhasketan Naik , Roll No. 710EE1061***, in partial fulfillment of the requirements for the award of degree *of B.Tech & M.Tech Dual In Electrical Engineering (**Electronics system and Communication**)* to the *National Institute of Technology, Rourkela* , is a bonafide record of work carried out by him under my guidance and supervision.

Place: NIT Rourkela

Date:

Prof. Susmita Das

Professor

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ABSTRACT

Utilization of available radio spectrum has always been a matter of concern now a days due to the growing interests of wireless applications. This is due to the fact that spectrum is a scarce and precious natural resource. Then again, a static spectrum allocation policy adopted by government of many countries has prompted underutilization of spectrum because a vast segment of licensed radio spectrum is not viably used. Cognitive radio is a propelled innovation in the modern wireless communication system which gives a new and diverse approach to enhance utilization efficiency of available spectrum resource. Spectrum Sensing is one of the key tasks for Cognitive Radio which prevents the unwanted interferences with authorized users to recognize available radio spectrum and enhance the usage of spectrum. It helps to recognize the unutilized spectrum bands also known as spectrum holes. A comparative study for various spectrum sensing schemes has been presented in this paper.

Several spectrum sensing strategies exist in the literature. Many Non-cooperative detection schemes have been incorporated in this paper. However, detection performance is frequently traded off with multipath fading receiver uncertainty and shadowing problems. To moderate the effect of these problems, Cooperative Detection has been demonstrated to be a promising technique to enhance the performance of detection by combining sensing information of multiple cognitive radio users. This thesis is extensively based on the analysis of various spectrum sensing technology through simulation results using TMS320C6713DSK and Code Composer Studio by Texas Instrument (TI) and then compared with the results obtained from MATLAB.

TABLE OF CONTENTS

ABBREVIATIONS

FCC	:	Federal Communication Commission
CR	:	Cognitive Radio
CE	:	Cognitive engine
MFD	:	Matched Filter Detection
CFD	:	Cyclostationary Feature Detection
US	:	United States
PU	:	Primary User
SU	:	Secondary user
DSA	:	Dynamic Spectrum Access
SDR	:	Software Defined Radio
IEEE	:	Institute of Electrical and Electronics Engineers
AWGN	:	Additive White Gaussian Noise
SNR	:	Signal-to-Noise Ratio
BPSK	:	Binary Phase Shift Keying
FC	:	Fusion centre
TI	:	Texas Instruments
CCS	:	Code composer studio
IDE	:	Integrated development environment
DSP	:	Digital signal processing
DSK	:	Digital signal processor kit

LIST OF FIGURES

1

INTRODUCTION

Wireless communication has made a transformation in our lives for nearly a decade now. New gadgets in this field has capability of offering higher information rates and creative services. Licensed and unlicensed spectrums are available for various kind of wireless applications and services. Yet with the exponential rise in wireless gadgets and their usage, the unlicensed spectrum is turning out to be rare. Static spectrum allocation policy is in practice at present due to which bandwidth in unlicensed bands is becoming rare and for licensed bands it is either underutilized or unoccupied.This spectrum inefficient usage arises due to the static spectrum assigning policy adopted by the governments of all the countries.Answer to this inefficient spectrum usage is dynamic spectrum access and allocation. Hence, the idea of Cognitive Radio gains a lot more importance because of its permission to licensed users to access the licensed band in a dynamic and opportunistic manner. However various regulatory bodies are working with much strictness for the protection of licensed users.

The next section of this chapter elaborates the static frequency assignment policy along with adverse impact of it on the spectrum usage.

The concept of CR is then discussed in detail. This ongoing chapter has been concluded by final objective of the research work and layout of the thesis.

1.1 MOTIVATION

FCC produced a report in 2002 which states that the spectrum usage of the bands less than 3 GHz is 5.2% only in USA at any given location and time . For mobile radio communication system the demand of radio frequency spectrum is rising exponentially day by day.The static spectrum allocation policy by government is solely responsible for the inefficient spectrum utilization and spectrum scarcity problem.Because of W-LAN, Bluetooth application, cordless phones and many other wireless devices the ISM bands are overcrowded and congestion is rapidly increasing. In this situation of inefficient RF spectrum usage and spectrum scarcity, there is a need of new technology that can efficiently utilize available spectrum resources in a dynamic way to fulfill the growing demands of bandwidth for different applications. This new system should be able to sense the spectrum, detect spectrum holes and utilize these spectrum holes and hence improving overall spectrum usage. Spectrum holes are frequency bands assigned to licensed users but these band remains unoccupied for a longer period of time, in a particular geographical region. Spectrum holes are shown in the figure below :

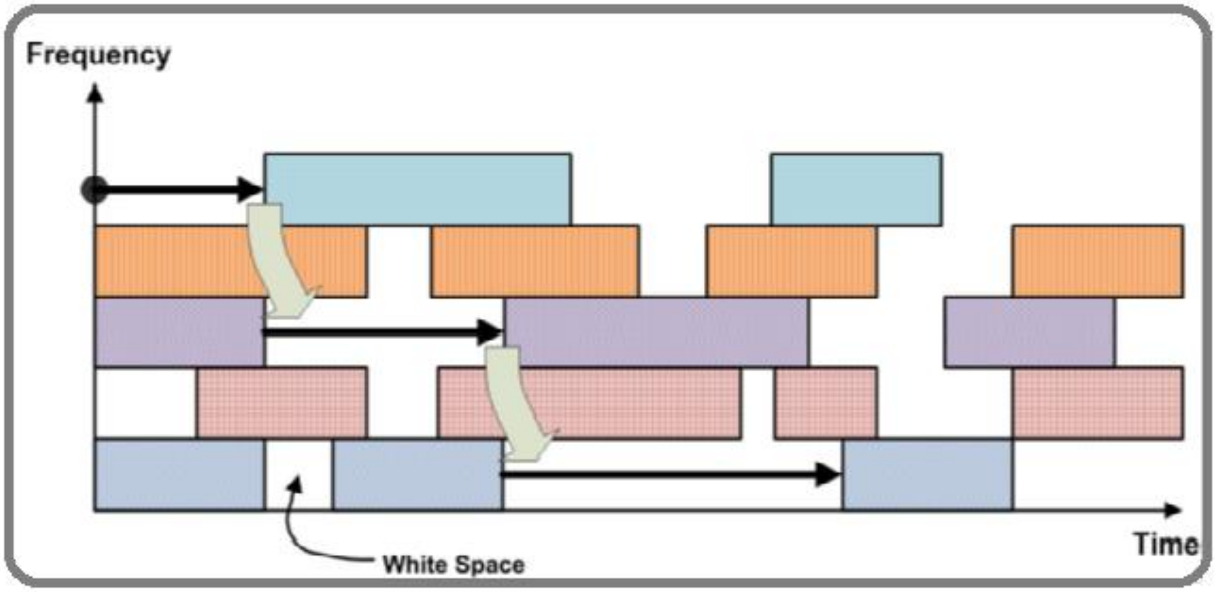


Fig 1.1 - Spectrum holes

Cognitive radios has the capability to sense the environment which are changing continuously and adapt itself in a intelligent manner by altering its parameter like frequency, type of modulation used, spread code, power etc .Cognitive radios should be so intelligent that it could learn and decide their operating parameters and alter their transmission and reception parameters to meet the performance requirements. Cognitive radio operations are regulated by Cognitive engine . The cognitive engine works in accordance with the cognitive cycle . The cognitive cycle involves various steps which are shown in fig.3. Cognitive cycle involves the task to analyse the Radio frequency stimuli from outside environment and sense the spectrum holes. It also involves the tasks like transmission power control and spectrum management after sensing the spectrum holes to ensure spectrum access free from interference.

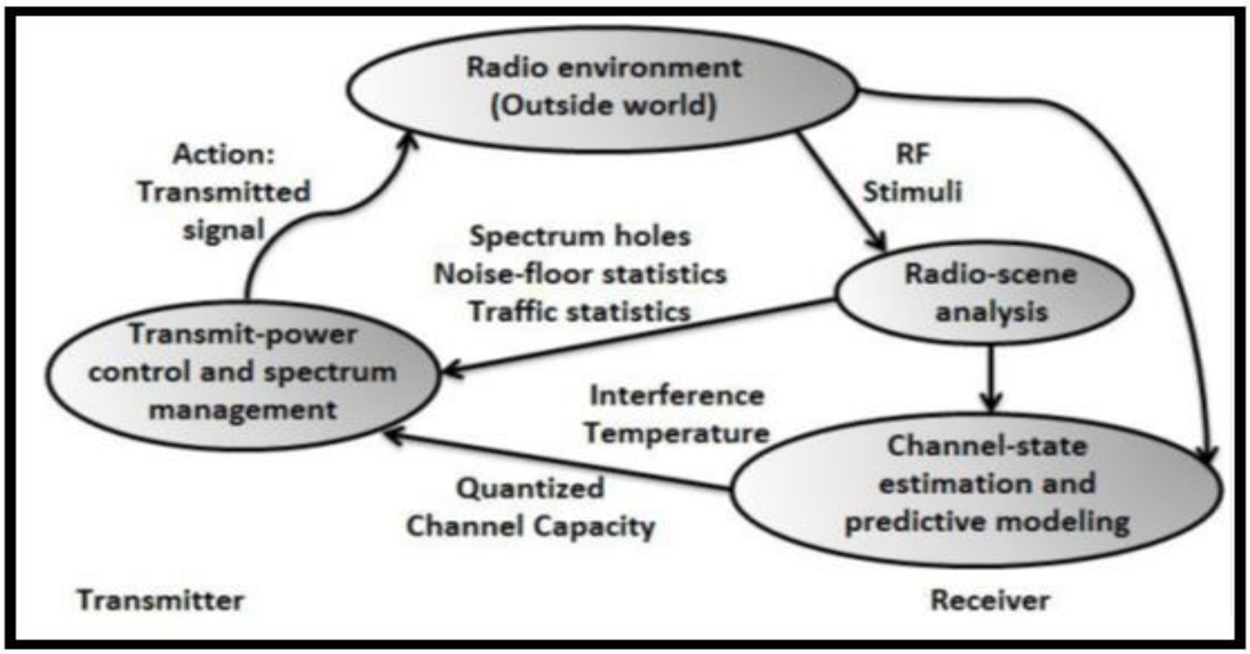


Fig. 1.2-Cognitive Radio cycle

The cognitive engine(CE) does sensing, analyzing, learning, making decisions and reconfiguration process .Cognitive radio networks (CRN) consist of two types of users, primary (licensed) and secondary (unlicensed or cognitive) users. Licensed users have the priority for the utilization of the licensed band of spectrum .On the other hand unlicensed users can communicate in an opportunistic manner in licensed spectrum band by altering their communication parameters in an adaptive manner when white spaces are readily available.

1.2 KEY OBJECTIVE :

The objective of this research work is to implement various spectrum sensing schemes in Cognitive Radio network through a hardware platform. For this purpose TMS320C6713 DSK has been used as the signal processing kit and it is programmed using Code Composer Studio v3 software which supports C/C++ programming language.

1.3 LITERATURE REVIEW :

The under usage of spectrum and its scarcity has been addressed firstly in one of the report from FCC, the telecom regulatory body of USA presented **by H.Ronald Coase** in 1959,[8].A new technological invention has been found by **Joseph Mitolla III** and he coined the term Cognitive Radio through his publication in 1999,[2] to remove this spectrum utilization problem. In 2005, FCC presented a report which clearly shows that some parts of licensed spectrum remains vacant for long time under specific location.

Symon Haykin gave a definition of CR in his paper in 2005,[9].Afterwards **Clancy III et.al.** describes the dynamic spectrum access concept in his Ph.D dissertation in 2006,[10].Then spectrum hole concept was addressed by **I. F. Akyildiz et.al.** in 2006,[11].Transmitter detection schemes was discussed by **P. Karnik et.al.** in the year 2004 which gave the basic idea and concept of spectrum sensing, one of the key task of CR,[12].The energy detection concept is very old one which is first given by **H. Urkowitz** through his paper in 1967,[4].The idea that ED method doesn’t need the prior information of the licensed user and it is the simplest method in terms of implementation complexities is shown by **Md. Shamim Hossain** in his paper in 2012,[1].Comparison between the three transmitter detection method ED,MFD and CFD is given by **Eleptherios Chatziantoniou, Ben Allen** in the year 2006,[3].

Cooperative detection schemes was proposed to overcome the effect of fading ,shadowing present in existing detection methods by **D,Teguig, B.Scheers** in 2012,[5]. The same cooperation technique has also been addressed in the paper [6] and [7].

1.4 THESIS CONTRIBUTION :

- The cooperative spectrum sensing techniques has been discussed under which hard decision and soft decision fusion scheme comes and their performance curves were compared with existing MFD, ED and CFD schemes.
- The simulation results obtained for different spectrum sensing techniques through MATLAB is compared with the results obtained by programming the TMS320C6713 DSK dsp kit.

1.5 THESIS ORGANIZATION :

This project report is arranged in six chapters. The ongoing chapter provides a detail idea to the spectrum scarcity problems, static spectrum assigning policy, cognitive radio(CR) and spectrum sensing.

Chapter 2: The second chapter gives a complete description of Cognitive Radio(CR) covering its history, definitions by various organisations, uses ,Pros and cons.

Chapter 3: The third chapter gives an idea to various spectrum sensing technique that are exist. Sensing hypothesis are also discussed in detail and three basic detection schemes ED, MFD and

CFD are explained in detail with the help of formulation and simulation graphs which validate the theory. Comparison of this three schemes were done on the basis of simulation curves.

Chapter 4: This chapter describes the Co-operative Detection scheme and illustrates the performance of the hard and soft decision fusion techniques in comparison to the existing transmitter detection techniques through MATLAB simulation.

Chapter 5: This chapter gives a brief introduction of Code composer studio and TMS320C6713 DSK .the results obtained from this hardware platform is then compared with the simulation results through MATLAB for all the spectrum sensing techniques that are discussed in preveous chapters.

Chapter 6: The sixth chapter presents the conclusion for the whole research work and the future scope to the research that has been conferred in the thesis.

2

COGNITIVE RADIO: AN INTRODUCTION

2.1- Introduction

Cognitive Radio as an extention of software defined radio appeared as a new evolution in the field of wireless communication in the year 1999.It is an intelligent radio with its associated network elements which communicate in such a way that it can adjust its network parameters in accordance with the need of the user and at the same time it learns from the results .Since then a tremendous amount of research work is going on to realize this technology.Many of the regulatory bodies in Europian countries and USA have acknowledge the importance of this intelligent system in the field of spectrum allocation.Inspite of all the progress it remained a research entity by today and wireless market is still awaiting its mass deployment and commercialization. Within a decade after CR is introduced FCC implemented a number of policies in spectrum assignment to provide secondary accessibility to unlicensed users on TV bands.This encouraging move compelled all the regulatory bodies to realize the underutilization of radio spectrum. CR has many tasks to perform out of which Spectrum sensing is the most crucial one.There are many techniques to detect the spectrum which are thoroughly discussed in the next chapter.

2.2 History of CR :

Many factors are there in the development process of CR technology. But the key factor has been the growing demand of radio spectrum and for an efficient communication system with better speeds.Due to this many incentive measures have been taken to manage the spectrum efficiently. The CR concept was presented by J. Mitola-III in one of the seminar at the Royal Institute of Technology in Stockholm in 1998 and published in a paper by J.Mitola and Gerald Q. Maguire, in 1999. Many telecom regulatory agencies around the world have found that a greater portion of radio spectrum was underutilized . Agencies like FCC in USA and Ofcom in UK have been taking into account that whether to give permission to unlicensed users in the bands of licensed users only if it would not interfere with them.These are the initiatives which focused CR research in the field of dynamic spectrum access.

2.3 .Pros ,Cons and uses of CR:

Some pros and Cons are there for CR which is quite similar as that of the SDR. Yet CR is the prior choice over the conventional radio as it can observe, adapt and has intelligence qualities simultaneously.

USES OF CR:

- Improvement in usage of spectrum
- Broadband services
- Communication at the time of emergrncy.
- Reliability increament in communication.
- Economically viable radio.

PROS OF CR:

- Spectrum usage in an efficient way
- Flexibility in control
- Less amount of coordination than traditional radio

CONS OF CR:

- Maintanence of high data rate.
- Security problem
- Wrong detection of spectrum occupancy for spread spectrum users.
- Cost to the end user.

3

SPECTRUM SENSING TECHNIQUES

Spectrum sensing is the most important task of CR Network.Cognitive radio is always enabled to be receptive towards the changes in radio environment.By spectrum sensing task CR has the facility to detect the spectrum holes.

3.1 INTRODUCTION

The basic demand of CR network is that the unlicensed usersshould have the capability to detect the licensed users and access the unused licensed bands but when the licensed user occupies its band CR should vacant the space instantaneously so as to counteract the interference effects.

One of the crucial task of CR is to detect the spectrum holes present in the licensed band .New spectrum sensing techniques are evolving day by day and many researchers are trying to figure out the most reliable schemes for CR networks. Its always been tedious task to identify the chanell between licensed (PU) user transmitter and cognitive user.Hence transmitter detection schemes has its own importance in the field of spectrum sensing.

3.2 Spectrum Sensing Hypothesis:

The idea of transmitter detection is to detect the weak signals between PU and CU.This detection technique is based on a binary hypothesis as follows:

$H0$: $x(n)=w(n)$ $\quad ,n=1,2,3……….N$

$H1$: $x(n)=h.s(n)+w(n)$ $\quad , n=1,2,3……….N$

Where $x(n)$: Received signal by CR

$s(n)$: Signal transmitted from PU

$w(n)$: Additive white Gaussian noise(AWGN)

h : Chanell gain

H_0 : Channel is vacant given that PU is absent

H_1 : Channel is occupied given that PU is present

From the above binary hypothesis three performance index for this detection methods are:

- Probability of detection (P_d): Chanell detected as vacant when it is really vacant.
- Probability of false alarm (P_f): Channel detected as occupied but in reality it is vacant
- . Probability of miss-detection (P_m) : Channel is detected as vacant but in reality it is occupied

In probability terms these index can be refered as:

P_d= Prob (H_1/H_1)

P_f=Prob (H_1/H_0)

P_m=Prob (H_0/H_1)

3.3 Spectrum sensing techniques:

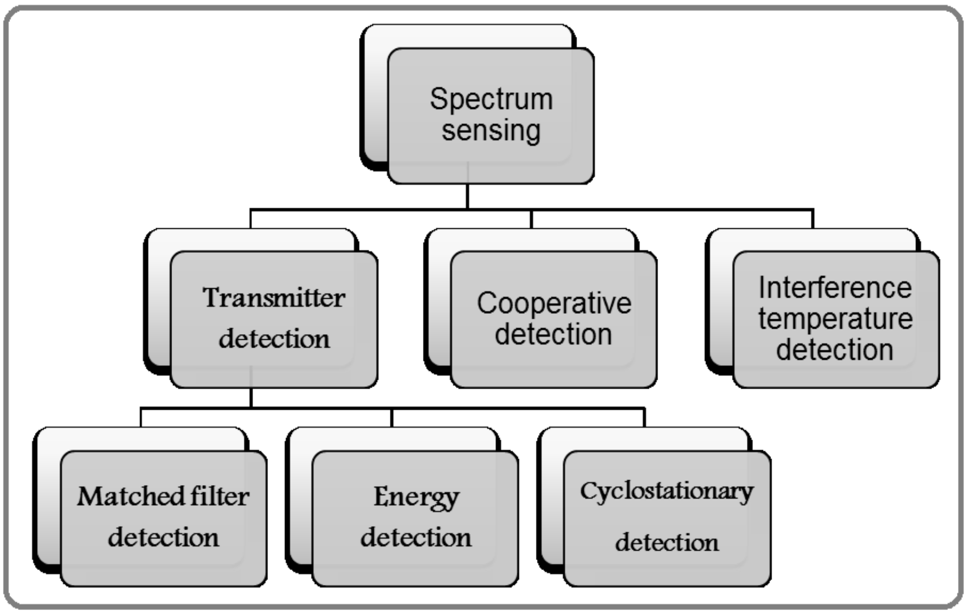


Fig 3.1. Classification of Spectrum Sensing techniques

Spectrum sensing techniques are categorized into three types which are transmitter detection ,cooperative detection and interference based detection as shown in the above figure. The key function of transmitter detection technique is to analyse the received signal.Transmitter detection is also known as non-coopoerative detection technique.This scheme is further classified into three types which are Matched filter detection(MFD),Energy detection(ED), and Cyclostationary feature detection(CFD).in the next section all the transmitter detection techniques has been discussed wth detail mathematical formulas and theory.

3.3.1 Matched Filter Detection (MFD):

MFD is one of the prominent detection technique where information from a known signal is decoded at the reciver end .This method works in coherent detection concept. Matched filter is a linear filter which increase the signal to noise ratio(SNR) of the PU under AWGN at user terminal of CR network. In MF convolution of received signal with a signal whose impulse response is time shifted version of a known signal is performed.

This technique is generally used when a prior information like spread code,modulation type, shape of the pulse etc. The block diagram of MFD technique is shown below:

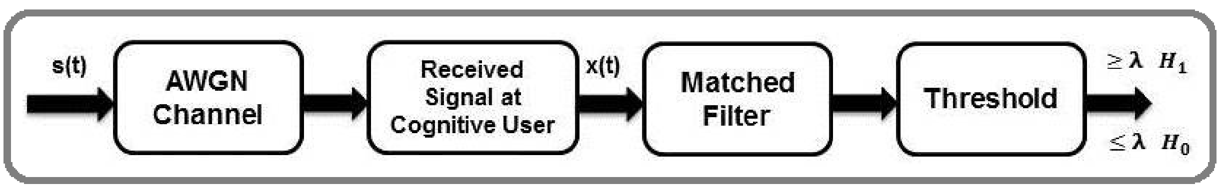


Fig. 3.2. Block diagram for MFD technique

The output from MF is then compared with a threshold which is pre determined to find whether the licensed spectrum is occupied or vacant. Security of the PU is a big concern in MFD as all the information is accessed by the cognitive user.As in the case of coherent detection synchronization between the user terminal of PU and SU is done in this method by which fading occours and eventually performance degraded.

Mathematically MFD is represented as:

$$D(x) = \frac{1}{N}\sum_{n=0}^{N-1} x(n) \times s(n)$$

Where, s(n) = prior known signal, $\sigma_n^{\,2}$

D(x) = test statistics.

Test statisics in MFD technique is as follows:

$$D(x) \sim \begin{cases} N(0, P\sigma_n^2 /N) & H_0 \\ N(NP, P\sigma_n^2 /N) & H_1 \end{cases}$$

Where, P =average PU signal power

$\sigma_n^{\,2}$ = noise variance.

Spectrum inhabitance for the PU can be written as follows:

$$\begin{cases} D(x) > \lambda\,, & H_1\text{: } licenced\ terminal\ is\ present \\ D(x) < \lambda\,, & H_0 : licenced\ terminal\ is\ absent \end{cases}$$

Where, λ =Preset threshold value

The mathematical expression for probability of detection (P_d), probability of false alarm (P_f), and probability of mis-detection (P_m) are derived as:

$$P_d = \Pr\left(D(x) > \lambda/H_1\right) = Q\left(\frac{\lambda - P}{\sqrt{P\sigma_n^2 /N}}\right)$$

$$P_f = \Pr\left(D(x) > \lambda/H_0\right) = Q\left(\frac{\lambda}{\sqrt{P\sigma_n^2 /N}}\right)$$

$$P_m = 1 - P_d = 1 - Q\left(\frac{\lambda - P}{\sqrt{P\sigma_n^2 /N}}\right)$$

3.3.2 Energy Detection (ED):

Difficulty arises in MFD technique when sufficient information about the PU is not found in the SU terminal. ED is the mostly used scheme as it does not require prior information about the PU and is the simplest of all in terms of implementation complexity. ED technique may only need the information about the SNR of PU for calculating the threshold value to compare its output.The block diagram for this scheme is as follows:

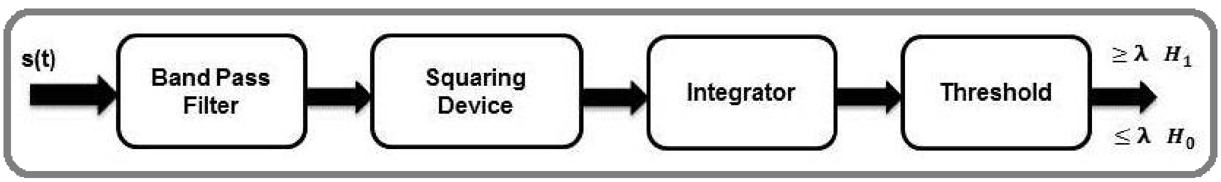


Fig. 3.3. Block diagram for ED technique

For calculating the signal energy of PU the output from the Band pass filter is squared and integrated and then this energy is compared with the predetermined threshold value for spectrum occupancy details of PU. ED is also known as blind detection technique. This scheme has some major drawbacks as follows:

- High sensing time
- Unable to differentiate between PU ans SU signals
- Low performance when noise uncertainty is there.

The mathematical expression for energy can be given as:

$$E = \sum_{n=0}^{N-1} |x(n)|^2$$

This is also the index used for comparison with the threshold.

The test statistics for ED can be given as:

$$D(x) = \frac{1}{N}\sum_{n=0}^{N-1} [x(n)]^2$$

Where, D(x)= test statistic,

N= Number of sample.

For a single threshold value λ, presence or absence of licensed user can be declared as :

$$\begin{cases} D(x) > \lambda\,, & H_1 : licenced\ terminal\ is\ present \\ D(x) < \lambda\,, & H_0 : licenced\ terminal\ is\ absent \end{cases}$$

If we assume the noise variance is fixed and the noise uncertainty is not considered, from the central limit theorem

$$D(x) \sim \begin{cases} N(\sigma_n^2\,, \sigma_n^4\,/N) & H_0 \\ N((\sigma_n^2 + P), (\sigma_n^2 + P)^2\,/N) & H_1 \end{cases}$$

The mathematical expression for probability of detection (P_d), probability of false alarm (P_f), and probability of mis-detection (P_m) are derived as:

$$P_d = \Pr(D(x) > \lambda/H_1) = Q\left(\frac{\lambda - (P + \sigma_n^2)}{\sqrt{\frac{2}{N}}.(P + \sigma_n^2)}\right)$$

$$P_f = \Pr(D(x) > \lambda/H_0) = Q\left(\frac{\lambda - \sigma_n^2}{\sqrt{\frac{2}{N}}.\ \sigma_n^2}\right)$$

$$P_m = 1 - P_d = 1 - Q\left(\frac{\lambda - (P + \sigma_n^2)}{\sqrt{\frac{2}{N}}.(P + \sigma_n^2)}\right)$$

Where, Q(.)= Complementary cumulative distribution of standard Gaussian function

λ= Pre-determined threshold value.

3.3.3 Cyclostationary Feature Detection (CFD):

From the literature it can found that CFD scheme is bettr than MFD and ED schemes.In previous sections it is discussed that the MFD technique require a handful knowledge of the PU signal and it is more like a coherent detector whereas in case of ED technique has inability to differentiate between PU and SU signals and performance is dependent on noise variance.

Periodic signals are also called cyclostationary signals.Periodicity happens in the signal because of modulation,spread code,synchronization etc. But noise signal is a stationary signal with no periodicity.So by using correlation function noise can be retrieved from the received signal.The block diagram for CFD is as follows:

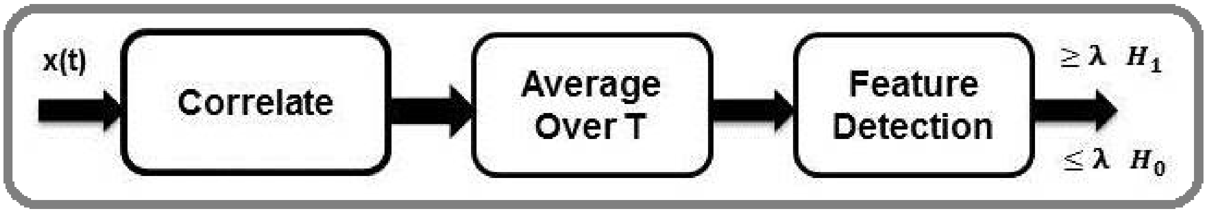


Fig. 3.4. Block diagram for CFD technique

Cognitive radio can sense any arbitrary signal even with some noise by the information related to its periodicity by using Spectral correlation functions which has the feature to evaluate the mean and autocorellation of any signal.The CFD scheme has the ability to differentiate between PU and SU signals due to which it outperforms the existing MFD and ED technique. However some major drawbacks are observation time which is large and has more computational complexity.

For a particular threshold value λ the probability equations can be given as follows:

$$P_d = \Pr\left(D(x) > \lambda/H_1\right) = Q\left(\sqrt{\frac{2 \times SNR}{\sigma_n^2}}, \frac{\lambda}{\sigma_A}\right)$$

$$P_f = \Pr\left(D(x) > \lambda/H_0\right) = exp\left(\frac{-\lambda^2}{2{\sigma_A}^2}\right)$$

$$P_m = 1 - P_d = 1 - Q\left(\sqrt{\frac{2 \times SNR}{\sigma_n^2}}, \frac{\lambda}{\sigma_A}\right)$$

Where , exp = exponential function,

SNR= $\frac{P}{\sigma_n^2}$,

$${\sigma_A}^2 = \frac{\sigma_n^2}{2N+1}$$

3.4 Simulation Results:

For the verification of the hypothesis given in the previous section ,simulation results were created for MFD,ED and CFD through MATLAB 2012b by a CPU of 3GB RAM and 2.1 GHz processor. Binary PSK signal is generated by multiplication of a random bit stream and asinusoidal career wave.The channel used is AWGN. Performance analysis is carried out on the basis of

- ✓ Plot of P_f vs P_d
- ✓ Plot of SNR vs P_d

The complete analysis of simulation curves for ED, MFD ,CFD are presented below :

3.4.1 Simulation for ED Technique:

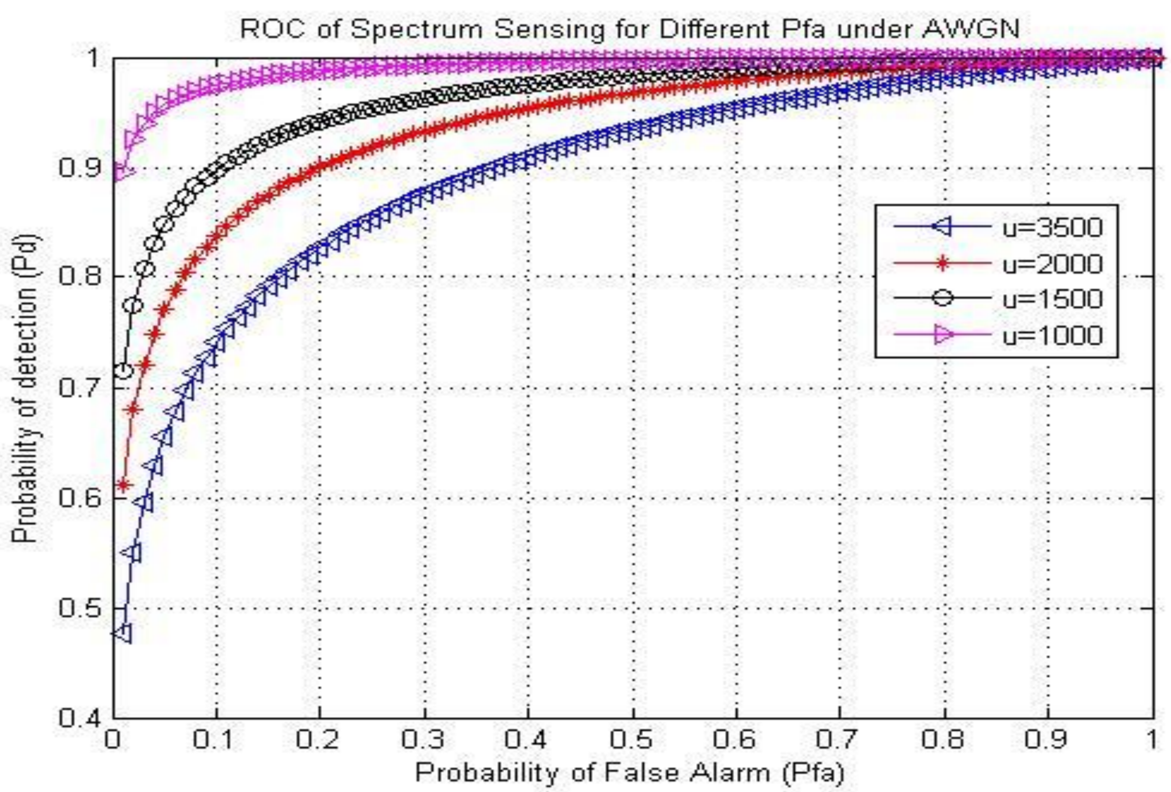


Fig. 3.5. ROC for ED with varying time bandwidth factor (u)

In Figure (3.5) the numerical results for Energy Detection technique is plotted between probabilities of false alarm (P_f) vs probability of detection (P_d), at different time bandwidth factor (u) = 2000, 1500, 1000. In this graph ,for 0 to 0.1, the value changes from 0.5 to 0.72, 0.6 to 0.82 and 0.71 to 0.9 for u = 2000 , 1500, 1000 respectively. Thus, it is clear that the detection performance improved as time bandwidth factor (u) is decreasing.

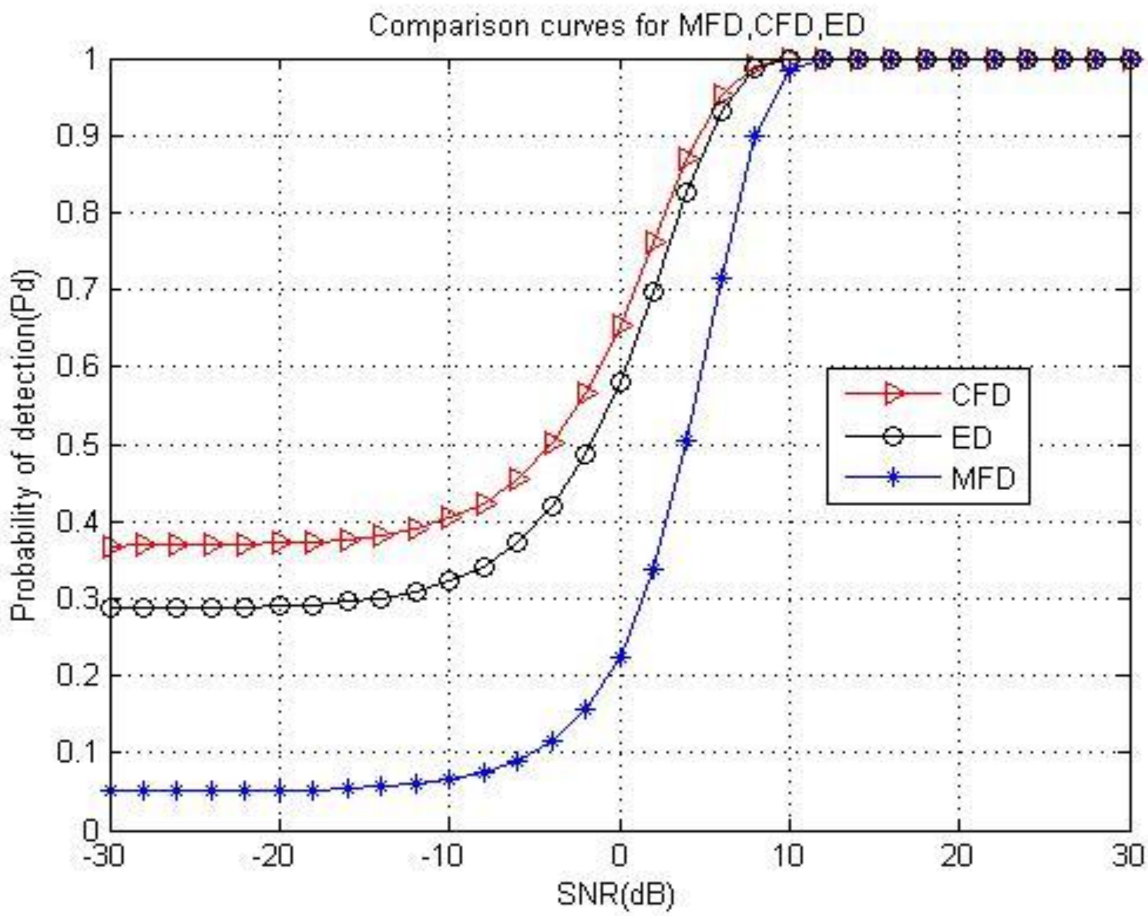


FIGURE 3-6: COMPARISON CURVES FOR MFD, ED AND CFD: N=1000, =0.1, SNR=-30:5:30

In figure (3.6), the value of at SNR= -10 dB are 0.07, 0.32 and 0.41 for MFD, ED and CFD respectively. All scheme achieve same (P_d) value at approximately SNR=10 dB, but below this SNR level, CFD outperforms the other two.

4

COOPERATIVE SPECTRUM SENSING

Cooperative sensing is proposed in the literature to eradicate some major spectrum detection problems which includes fading, receiver uncertainty and shadowing. The key idea of this detection scheme is to enhance the sensing performance by taking the advantage of spatial diversity, so as to protect the PU in a better way and decrease the false alarm to use the spectrum more efficiently.

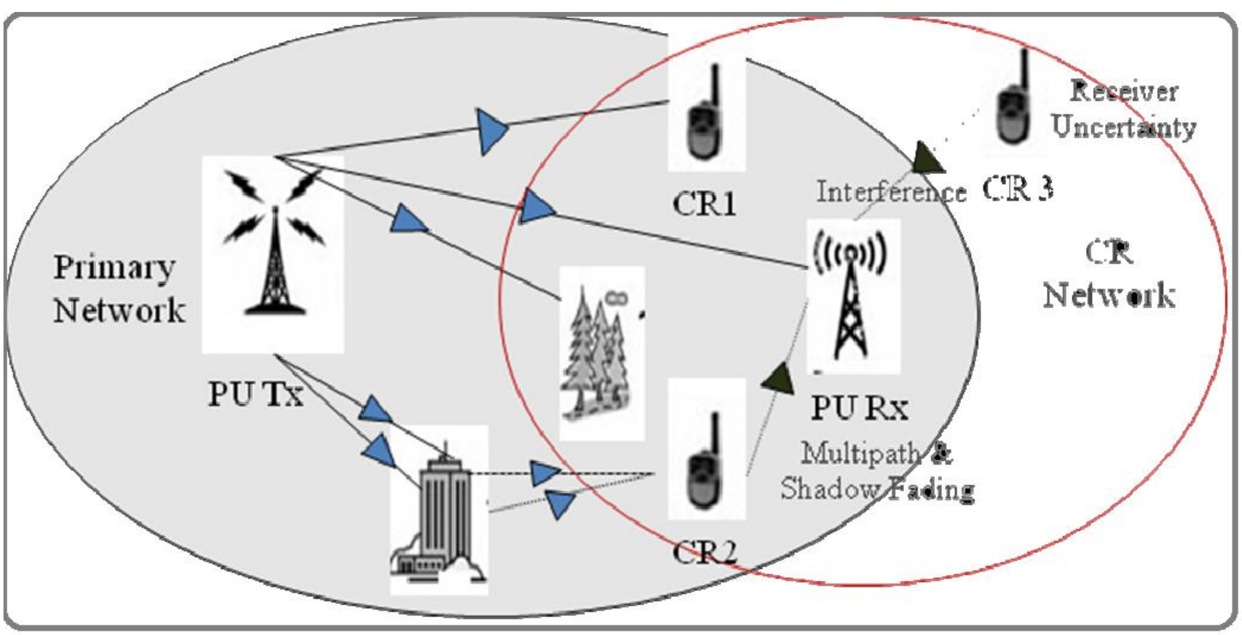


Fig. 4.1. Sensing problems (receiver uncertainty, multipath and shadowing)

INTRODUCTION:

To solve the terminal problems and to reduce the uncertainty for sensing of PU cooperative spectrum sensing scheme is recently got much attention from researchers. Also a large sensing time is needed for a single CR user for the detection of wideband radio spectrum.However these issues can be solved by cooperation between multiple CR user.The wideband spectrum is divided into multiple subbands and each CR is assigned a narrow subband. A base station also known as fusion centre (FC) is needed for receiving the decision from individual CR and making a final decision for the whole spectrum. The FC combines all the sensing information from each CR by implementing many data fusion schemes. There are two major data fusion rules discussed which are Hard decision and Soft decision. Under hard decision logical AND & OR rule comes and in soft decision includes SLC & MRC rule The main focus in further sections will be on these data fusion rules and their performance comparison. Before dscussing the fusion rules elaborately we need to get an idea of system model for this detection scheme which is presented in the next subsection.

SYSTEM MODEL:

Suppose k CR users cooperate each other in the cognitive radio network to detect the PU. Let N samples from the received signal are used by each individual CR to carry out local spectrum sensing.The sensing scheme can be described by a binary hypothesis as follows:

$$H0:\ x_k(n) = w_k(n) \qquad ,k=1,2,3\ldots\ldots\ldots K$$

$$H1:\ x_k(n) = h_k.s(n) + w_k(n) \qquad ,\ k=1,2,3\ldots\ldots\ldots K$$

Where, s(n)= PU signal samples

$W_k(n)$=noise in receiver for k^{th} CR user

h_k.= complex gain of chanell between PU and k^{th} CR user

$H0 =$ Channel is vacant given that PU is absent

$H1$ = Channel is occupied given that PU is present

By ED method the received energy for and k[th] CR user is:

$$E_k = \sum_{n=1}^{N} x_k^2(n)$$

For soft decision rule, each individual CR sends their results E_k to the FC. But in case of hard decision the CRs make one bit decision denoted by μ_k by comparing E_k and preset threshold λ_k .

$$\mu_k = \begin{cases} 1, & E_k > \lambda \\ 0 & , otherwise \end{cases}$$

Probability of detection and probability of false alarm for k[th] CR user is :

$$P_{d,k} = Pr\{\mu_k = 1|H_1\} = Pr\{E_k > \lambda_k|H_1\}$$

$$P_{f,k} = Pr\{\mu_k = 1|H_0\} = Pr\{E_k > \lambda_k|H_0\}$$

Let $\lambda_k = \lambda$ for every CR ,then for AWGN channel detection, false alarm and miss detection probability can have the expression as:

$$P_{d,k} = Q_m(\sqrt{2\gamma}, \sqrt{\lambda})$$

$$P_{f,k} = \frac{\Gamma(\mathrm{m}, \lambda/2)}{\Gamma(\mathrm{m})}$$

$$P_{m,k} = 1 - P_{d,k}$$

Where γ= signal to noise ratio (SNR)

m = time bandwidth factor

$Q_m(\ldots)$ = Marcum Q-function

Γ(.) =complete gamma function

Γ(.,.) = incomplete gamma function

HARD DECISION FUSION:

In this fusion rule every CR user decides whether the PU is present or absent and forward a one bit decision to the FC. Less amount of bandwidth is required for this method which is its key advantage.The binary decision used are 0 and 1 which signifies PU is present and absent respectively. After the binary decision reached to the node in FC there are basically two rules on the basis of which final decision is made. These are AND & OR logical rule explained below:

AND rule : According to this rule if all the CR user sent the one bit decision as '1' or '0' then the PU is present or absent respectively.The formulation of this rule can be:

$$H_1: \sum_{k=1}^{K} \mu_k = K$$

$$H_0: \ otherwise$$

The probability of detection, false alarm and miss detection for cooperative scheme is denoted by Q_d , Q_f and Q_m respectively.

$$Q_{d,and} = \prod_{k=1}^{K} P_{d,k}$$

$$Q_{f,and} = \prod_{k=1}^{K} P_{f,k}$$

$$Q_{m,and} = 1 - Q_{d,and}$$

OR rule : According to this rule if any one of the CR user sent the one bit decision as '1' then FC decides that the PU signal is present. The formulation of this rule can be:

$$H_1 : \sum_{k=1}^{K} \mu_k \geq 1$$

$$H_0 : \ otherwise$$

The probability of detection, false alarm and miss detection for this rule are :

$$Q_{d,and} = 1 - \prod_{k=1}^{K} (1 - P_{d,k})$$

$$Q_{f,and} = 1 - \prod_{k=1}^{K} (1 - P_{f,k})$$

$$Q_{m,and} = 1 - Q_{d,and}$$

SOFT DECISION FUSION :

In this fusion rule every CR user send the sensing result to the FC without performing local spectrum sensing individually.The final decision is given by FC by using some combining rules.The major combining rules in this detection techniques are square law combination (SLC) and maximum ratio combination (MRC). Performance of this rule is better than that of hard decision rule but at the cost of bandwidth.

Square law combination (SLC) : This is the simplest combination rule in which the calculated energy at each node is forwarded to the FC where their addition is done and the result is compared with a preset threshold to decide the presence or absence of PU. The test statistics for this rule is:

$$E_{slc} = \sum_{k=1}^{K} E_k$$

$$E_k = statistics\ from\ \ k^{th}\ CR\ user$$

The probability of detection, false alarm and miss detection for this rule are :

$$Q_{d,slc} = Q_{mK}(\sqrt{2\gamma_{slc}}, \sqrt{\lambda}\ )$$

$$Q_{f,slc} = \frac{\Gamma(\mathrm{mK}, \lambda\ /2)}{\Gamma(\mathrm{mK})}$$

$$Q_{m,slc} = 1 - Q_{d,slc}$$

$$where\ ,\quad \gamma_{slc} = \sum_{k=1}^{K} \gamma_k \quad ,\quad \gamma_k = recieved\ SNR\ at\ \ k^{th}\ CR\ user$$

Maximum Ratio Combination (MRC) : The only difference between SLC and this rule is that received energy from each CR user is multiplied with certain normalized weight and added whereas in SLC the energy are directly added. The received SNR from different CR user decides the weights to be assigned. The test statistics for this rule is:

$$E_{mrc} = \sum_{k=1}^{K} w_k E_k$$

The probability of detection, false alarm and miss detection for this rule are :

$$Q_{d,mrc} = Q_m(\sqrt{2\gamma_{mrc}}, \sqrt{\lambda}\ )$$

$$Q_{f,mrc} = \frac{\Gamma(\mathrm{m}, \lambda\ /2)}{\Gamma(\mathrm{m})}$$

$$Q_{m,mrc} = 1 - Q_{d,mrc}$$

$$where\ ,\quad \gamma_{mrc} = \sum_{k=1}^{K} \gamma_k \quad ,\quad \gamma_k = recieved\ SNR\ at\ \ k^{th}\ CR\ user$$

SIMULATION AND RESULTS:

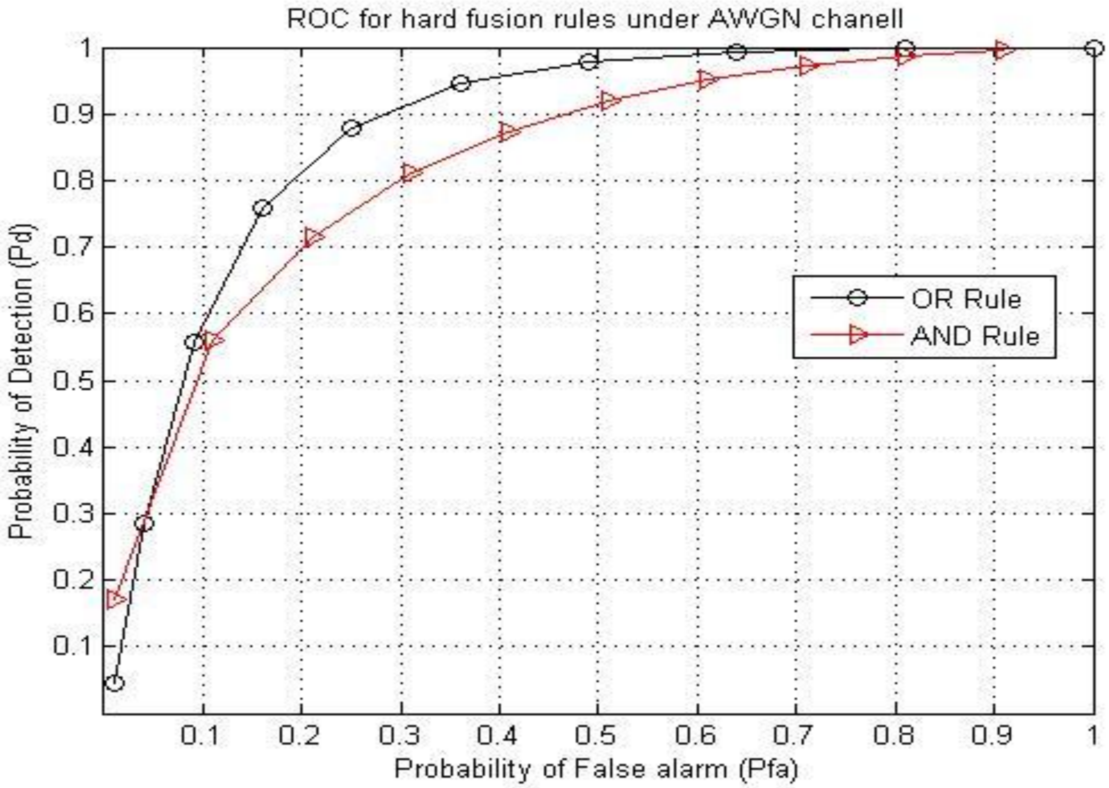


Fig. 4.2. Comparison between OR & AND Rule

Figure (4.2) depicts the numerical results for Hard Decision Fusion technique which belongs to Cooperative spectrum sensing scheme plotted between probabilities of false alarm (P_f) vs probability of detection (P_d) , when number of CR user = 5 . In the graph for P_f = 0.1 to 0.2 , the value of P_d varies from 0.52 to 0.7, 0.6 to 0.8 for Logical AND rule & Logical OR rule respectively. Thus, we can conclude that performance under OR rule is better than AND rule.

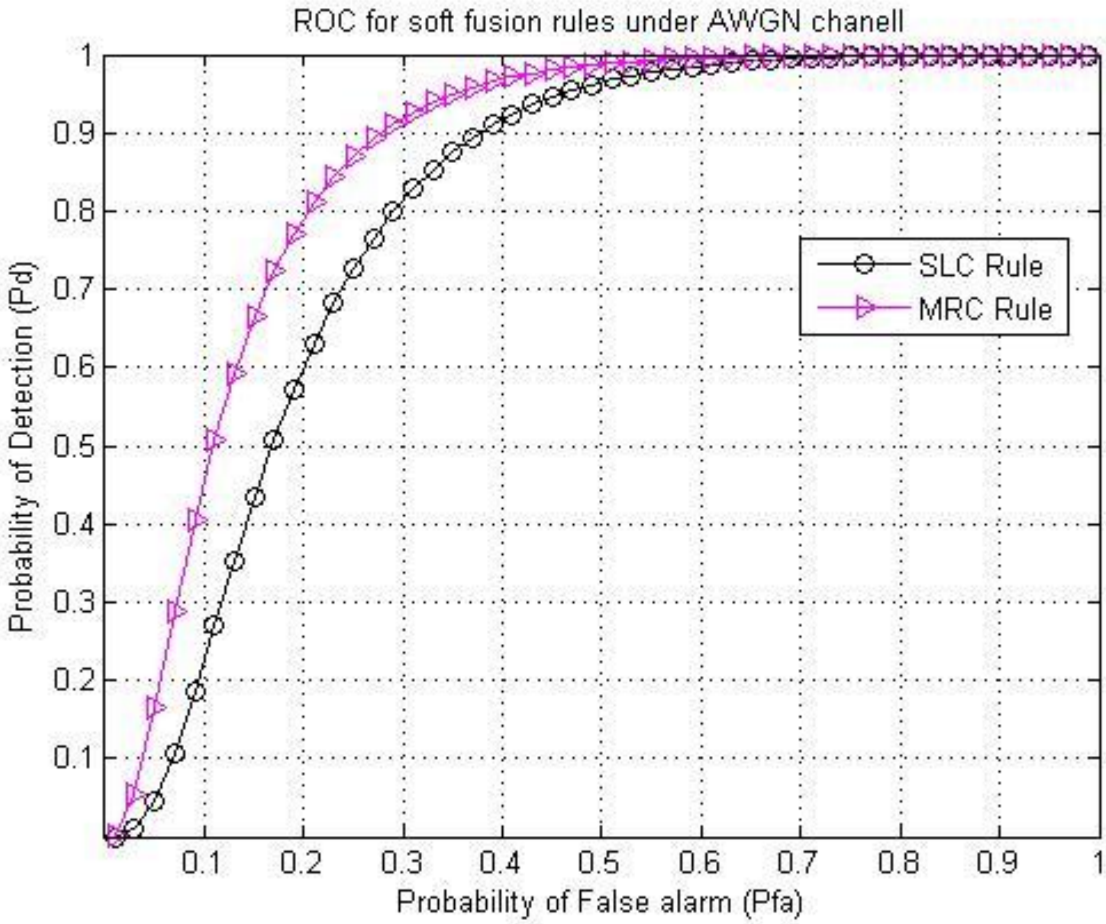


Fig. 4.3. Comparison between MRC & SLC Rule

Figure (4.3) depicts the numerical results for SLC rule and MRC rule which belongs to Soft Decision Fusion technique under Cooperative spectrum sensing scheme plotted between probabilities of false alarm (P_f) vs probability of detection (P_d), when number of CR user = 5 . In the graph for P_f = 0.1 to 0.2 , the value of P_d varies from 0.2 to 0.57, 0.43 to 0.8 for SLC rule & MRC rule respectively. Thus, we can conclude that performance under MRC rule is better than SLC rule in Soft detection technique.

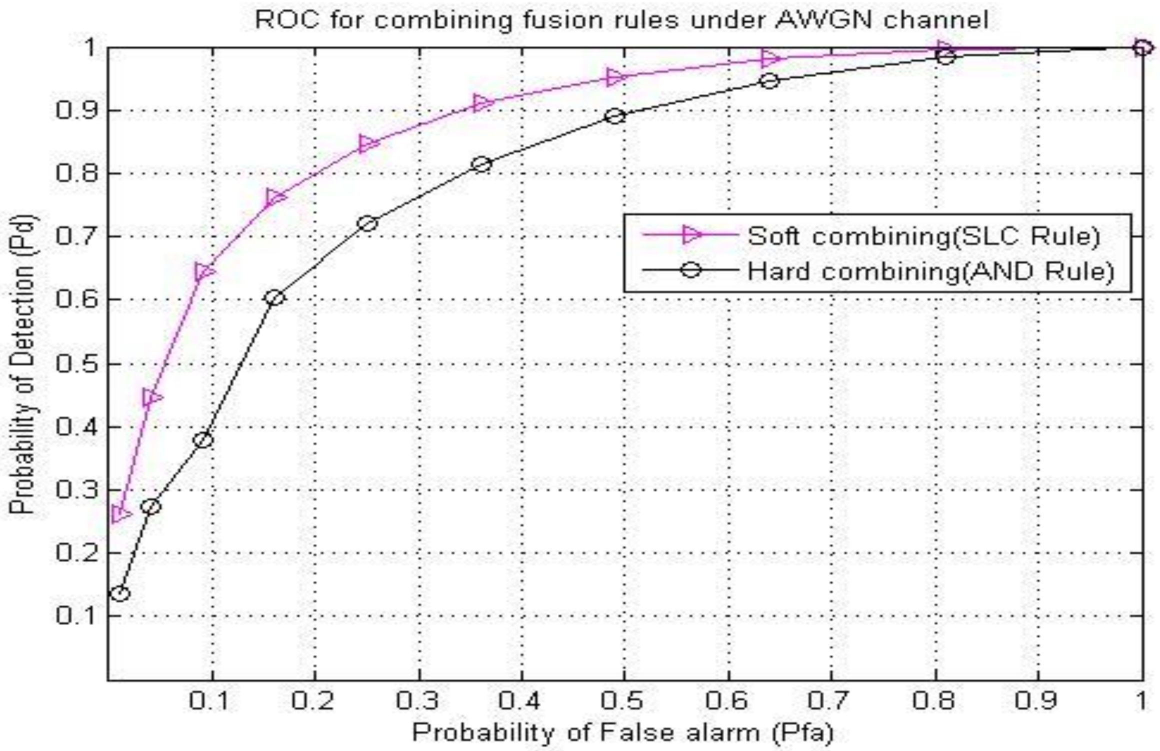


Fig. 4.4. Comparison between Hard & Soft fusion scheme

Figure (4.4) depicts the numerical results comparison for Hard Decision Fusion technique(AND Rule) and Soft Decision Fusion technique (SLC Rule) which belong to Cooperative spectrum sensing scheme plotted between probabilities of false alarm (P_f) vs probability of detection (P_d), when number of CR user = 5 . In the graph for P_f = 0.1 to 0.2 , the value of P_d varies from 0.4 to 0.64 , 0.63 to 0.8 for Logical AND rule under Hard Decision & SLC rule under Soft Decision Fusion respectively. Thus, we can conclude that performance under Soft combination is better than Hard combination.

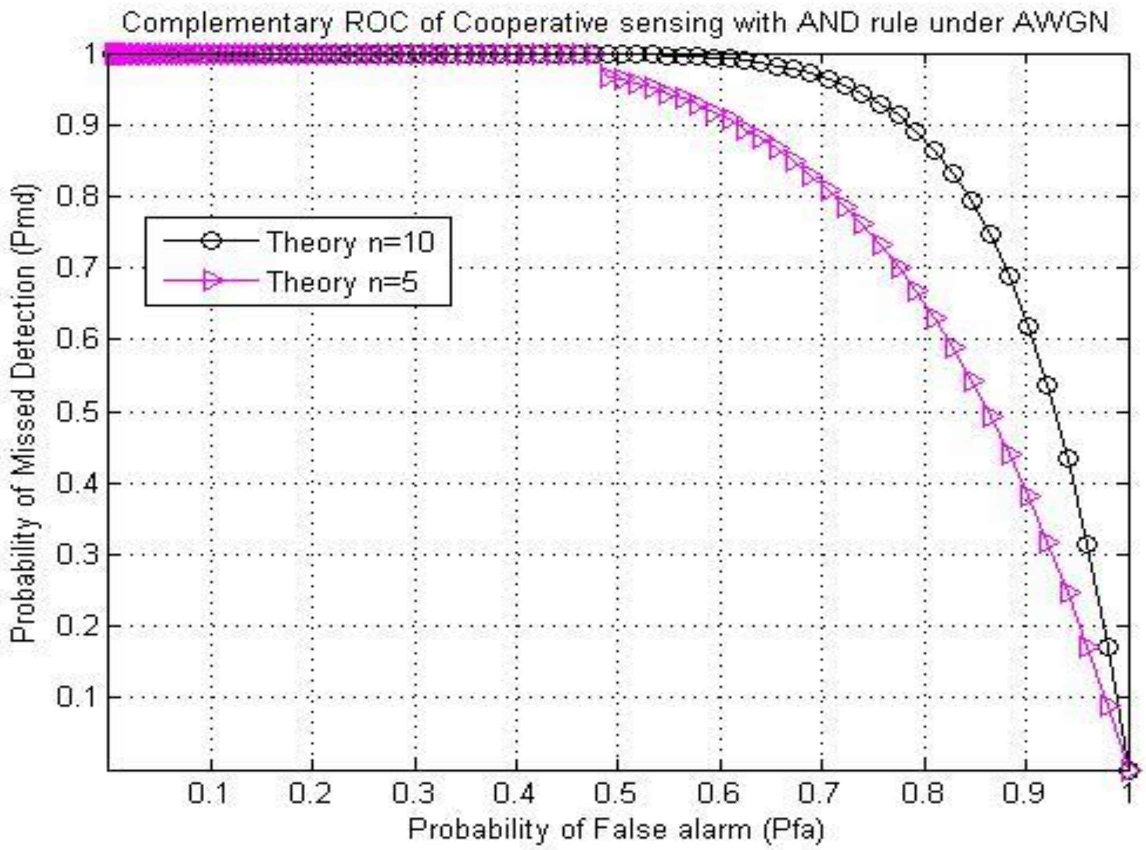


Fig. 4.5. ROC of AND rule for varying no. of CR users

Figure (4.5) depicts the numerical results comparison for AND Rule under different number of CRs for cooperation purpose plotted between probabilities of false alarm (P_f) vs probability of detection (P_d). In the graph for P_f = 0.6 to 0.7 , the value of P_d varies from 0.9 to 0.8 , 0.98 to 0.96 when number of CR user =5 and respectively. Thus, we can conclude that performance increases when number of CR users in the network for cooperation increases.

5

Code Composer Studio & TMS320c6713DSK

5.1 INTRODUCTION:

Over the past decade the importance of C/C++ programming language in the field of signal processing has increased tremendously. Responding to it Texas instrument Inc.(TI) has developed a silicon and compiler architecture for efficient performance of this languages .TI has included many features to this integrated development environment(IDE)tools. TMS320c6713DSK is a DSP kit developed jointly by TI and Spectrum Digital giving pace to the development of precise applications which is based on TI´s TMS320C6000 floating point DSP generation. The kit uses USB communication to connect with the PC. The Code composer studio (CCS) avails all the software requirement tools for the simulation of this DSP kit. IDE provides an application window where all the code can be developed. This window provides code entering, editing and after that its compilation ,building, execute and finally debugging the program. The next section describes details about TMS320c6713DSK and CCS and the entire procedure for the simulation of this DSP kit.

5.2 TMS320c6713DSK :

TMS320C6x family processors are the first to use veloci-TI architecture, which have implementation of VLIW based architecture. TMS320C62x is a 16-bit fixed point processor ,67x is a floating point processor with 32-bit integer support. The discussion in this chapter is focused on the TMS320C67x processor. The architecture and peripherals associated with this processor are also discussed. C6713 DSK is a standalone development platform from which users can able to evaluate and build many applications for TI C67xx DSP family. The DSP kit serves as a hardware design for TMS320C6713 DSP. Schematics, equations based on logic and application notes are available to make the hardware development easy. Programming of this DSP kit is done through CCS software.

Diagrams of TMS320C6713 DSK :

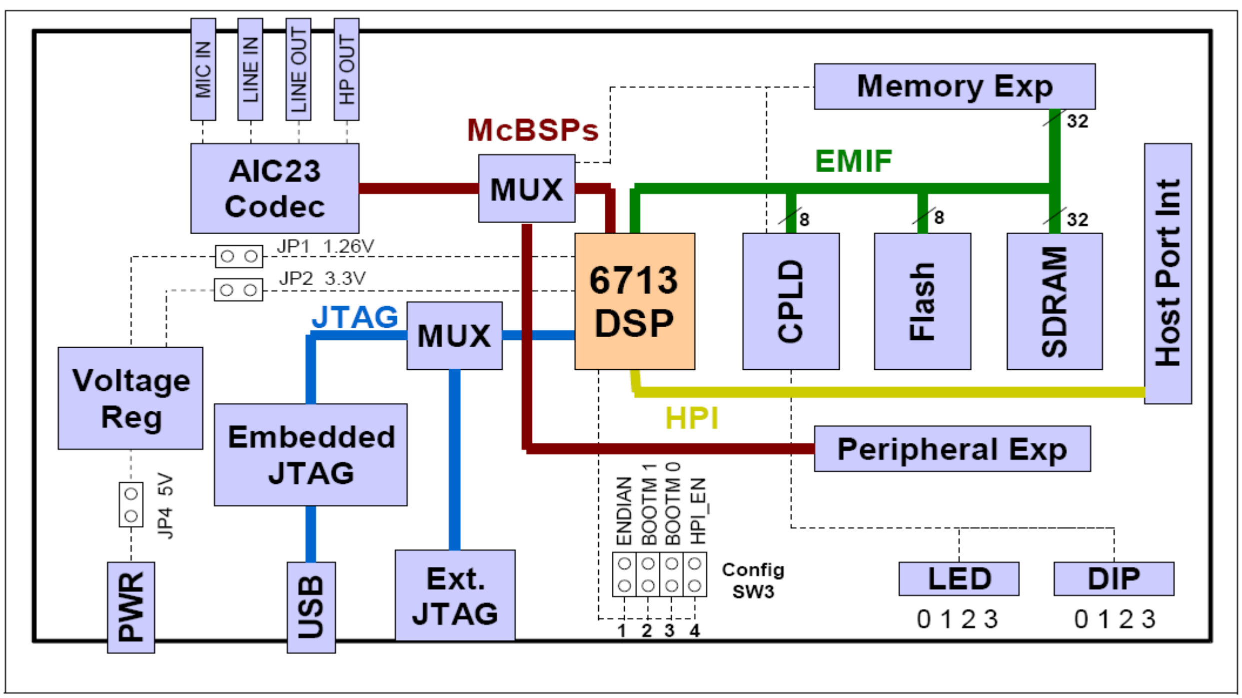


Fig.5.1. Block diagram for TMS320C6713 DSK

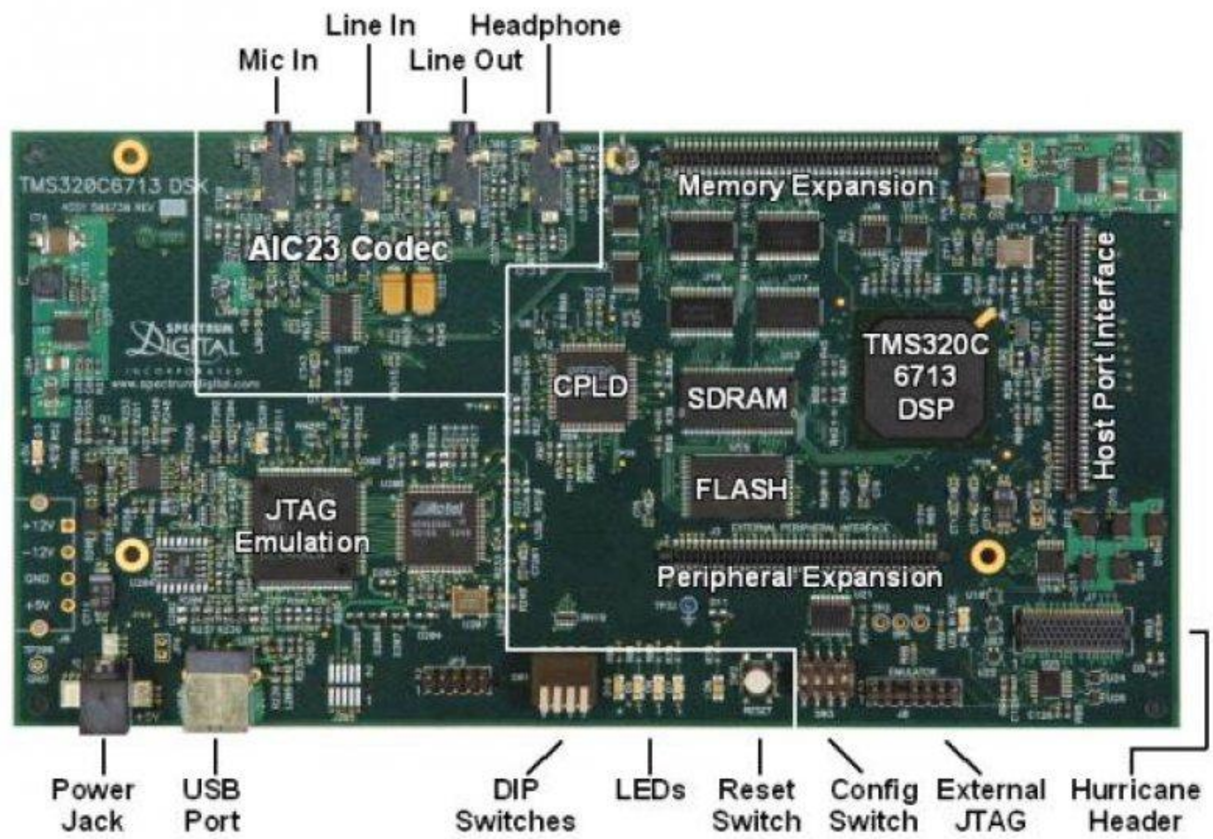


Fig.5.2. Board diagram for TMS320C6713 DSK

5.2.1 Features of TMS320c6713DSK :

The DSK is an on-board devices which suits a wide variety of application surrounding. Main features involves :

• TMS320C6713 DSP kit operating at 225 MHz from TI.

• AIC23 stereo codec

• 16 MB SDRAM

• 512 KB of NV Flash memory (256 KB usable at default setting)

• Four accessible LEDs , DIP switches

• Software board configuration by registers deployed in CPLD

• Boot options which is configurable.

• Expansion connectors which enable daughter card use

• JTAG emulation process by on-board JTAG emulator with USB as host

•Interface also known as external emulator

• voltage supply (+5V)

5.2.2 Basic Operation :

The DSP kit is intended to work with Code Composer Studio from Texas Instrument's IDE . Code Composer(CCS) communicates through on-board JTAG emulator with the board. To start CCS, instructions were followed from the Quick Start Guide of CCS. This process has installed all of the required tools, and drivers. After the installation is completed, these steps were followed to run the Code Composer Studio(CCS).

1) Power supply is connected to the DSP kit .

2) DSK is connected to a PC with a standard USB cable .

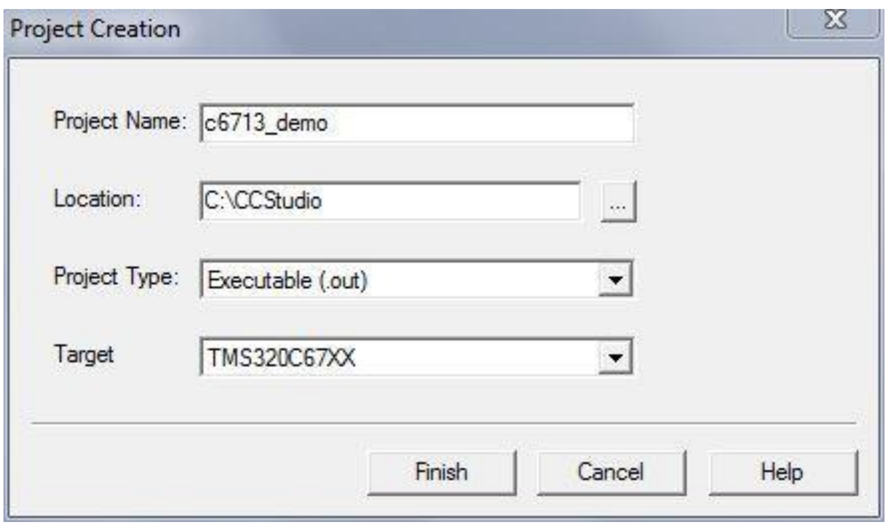
3) Code Composer from its icon on the desktop was is launched .

5.3 CODE COMPOSER STUDIO :

Code Composer Studio (CCS) is the coding platform for DSPs from TI. CCS V3.3 properties has been explored in this chapter. Code Composer Studio (CCS) is the programming, building, and debugging interface for DSPs from TI. Communication between CCS and C6713 DSK board is over embedded JTAG interface and it can exchange real-time data with the DSK board.

5.3.1 Creating a New Project :

A new project can be created by pressing "project" and "new" in CCS V3.3. For naming the project, "Project Name" tab can be used as in Figure 2.6. After clicking on "Finish", a blank project will be created.

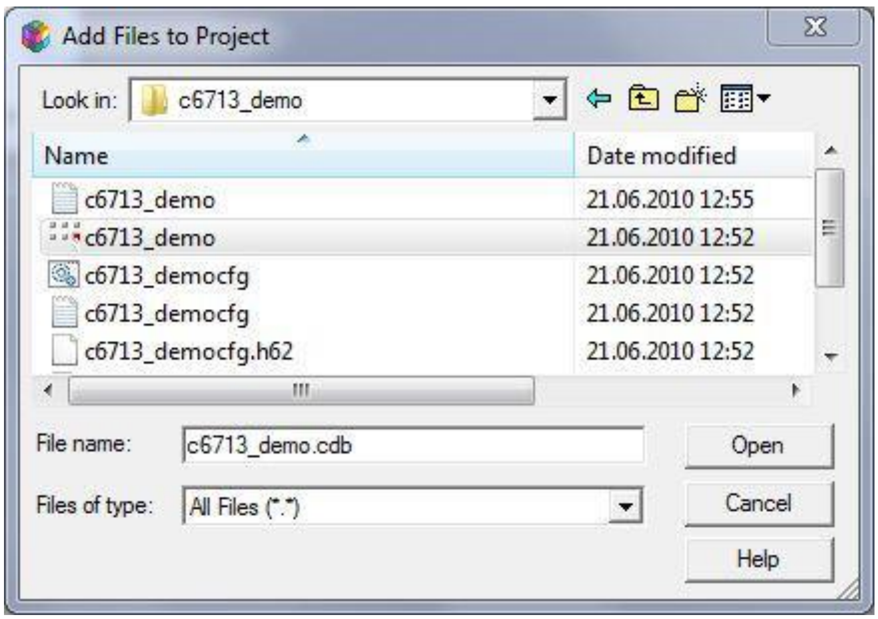


5.3.2 Bios Configuration :

Basic configurations should be adjusted to run the C6713 DSK board in correct order. Memory map, handling of interrupt, I/O control , and etc are covered in these configurations. For managing these configurations, DSP/BIOS is used. The OS and the program to run are embedded together to the DSP in the project. When program is running ,DSP/BIOS handles all necessary operations on the background.

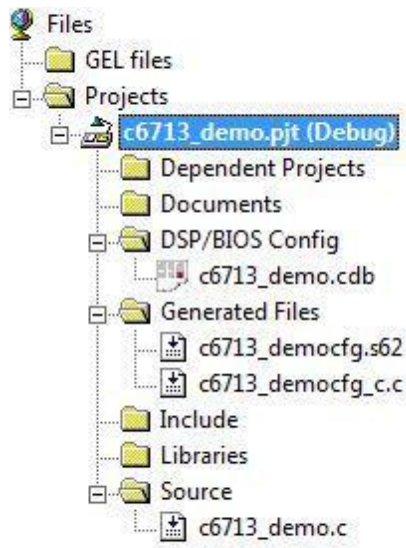
To setup DSP/BIOS ,“xxx.cdb”configuration file is used. By pressing “File→New→DSP/BIOS Configuration”, a new DSP/BIOS configuration file can be opened, and “dsk6713.cdb” can be selected .

We should save the configuration file by “File→ Save: c6713_demo.cdb”. Now, a new configuration file is created. However, it is not added to the project yet. It can be added to the project by “Project→ Add Files to Project..." and selecting the “c6713_demo.cdb” file as in Figure 2.10.



5.3.4 Creating the Source Code :

We should follow the "File→ New→ Source File" steps to create a source code. In Figure 2.12, a simple source code is there . Using “File→ Save c6713_demo.c”,we can save this code. Then we can add this file to project by "Project→ Add Files to Project...". It could be seen in the project tree as in Figure 2.13.



5.3.5 Running the Source Code :

The code is now ready to be built and run. To build the code,the steps "Project→Build" are followed. If there are no errors in the code, we could see a message similar to Figure 2.14.

```
Build Complete,
  0 Errors, 2 Warnings, 0 Remarks.
```

To run the code, these steps are followed:

i. File→ Load Program ...: Select the "experiment2_demo.out" under debug folder.

ii. Debug→ Reset Cpu

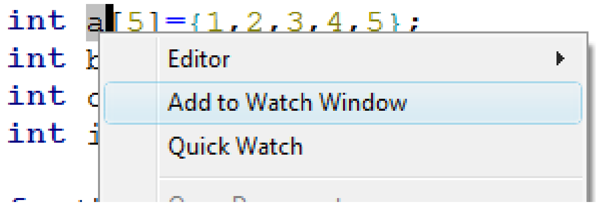
iii. Debug→ Restart

iv. Debug→ Go Main

v. Debug→ Run

5.3.6 Adding a Watch Window :

To see the values in the array variable, we can use the watch window. To add a variable to the watch window, we right-click on the variable and select "Add to watch window" as in Figure 2.16.



5.3.7 Plots :

For ploting of graphs the entire values of two arrays to be ploted are taken and inserted in Microsoft Excel sheet .

RESULTS :

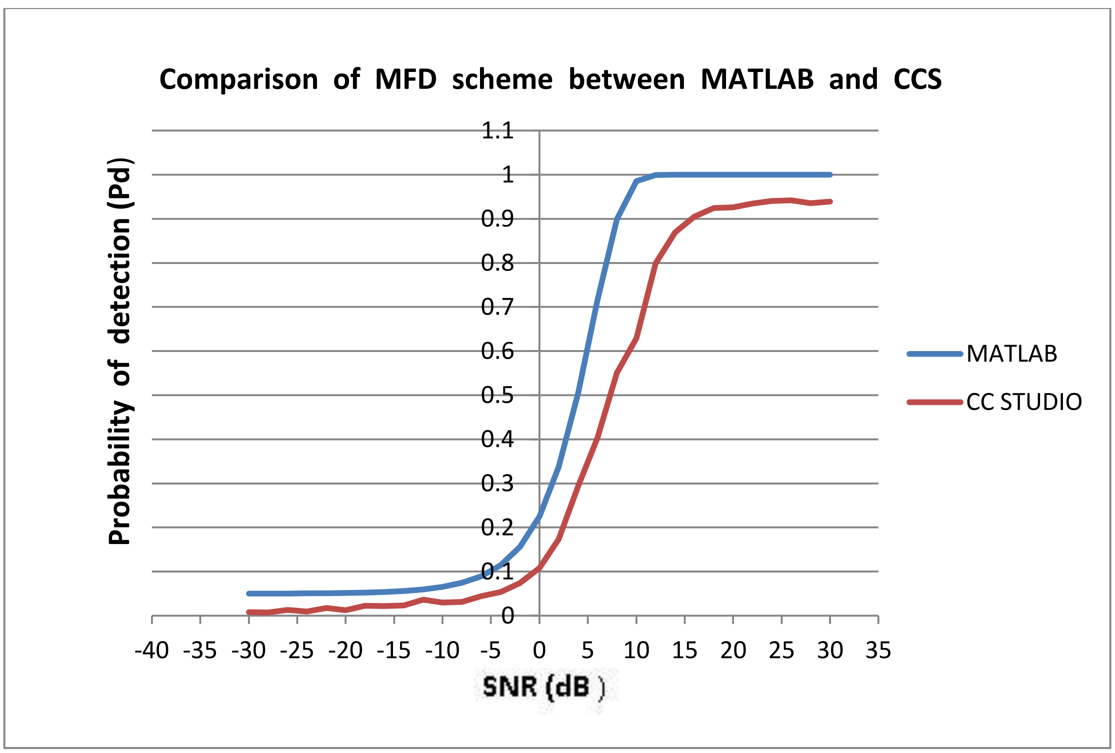


Fig. 5.3. Pd vs SNR for MFD scheme

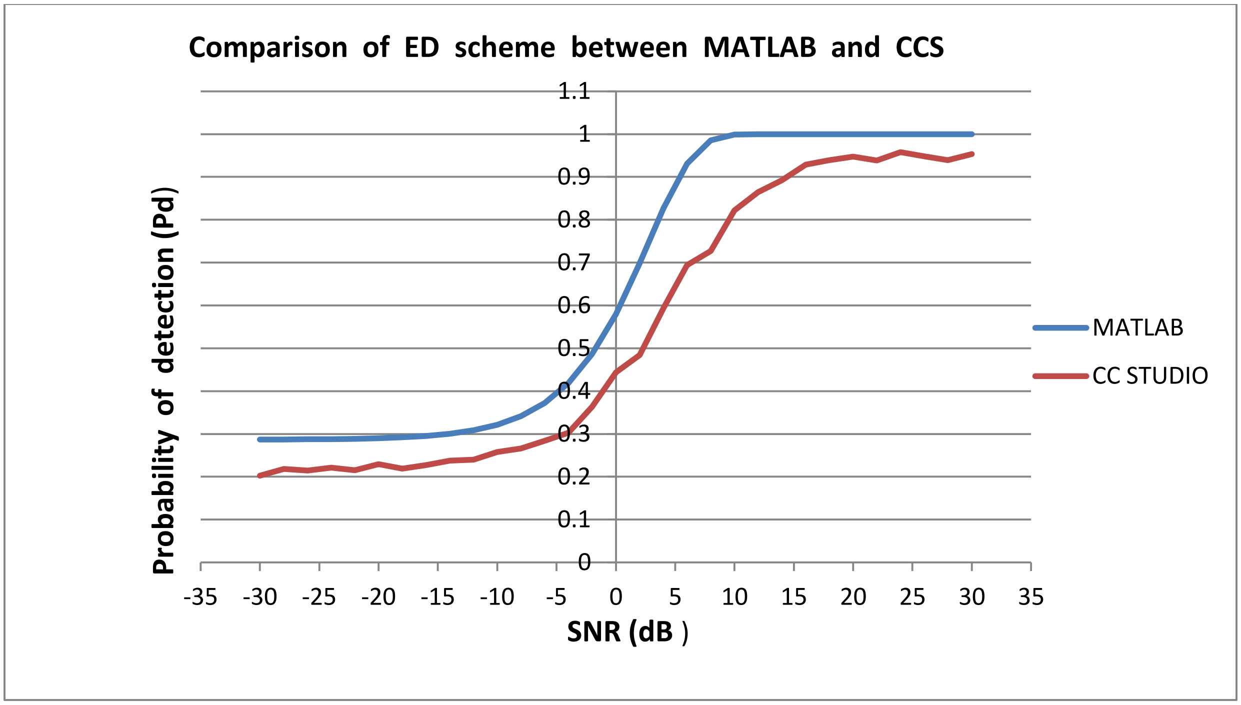


Fig. 5.4. Pd vs SNR for ED scheme

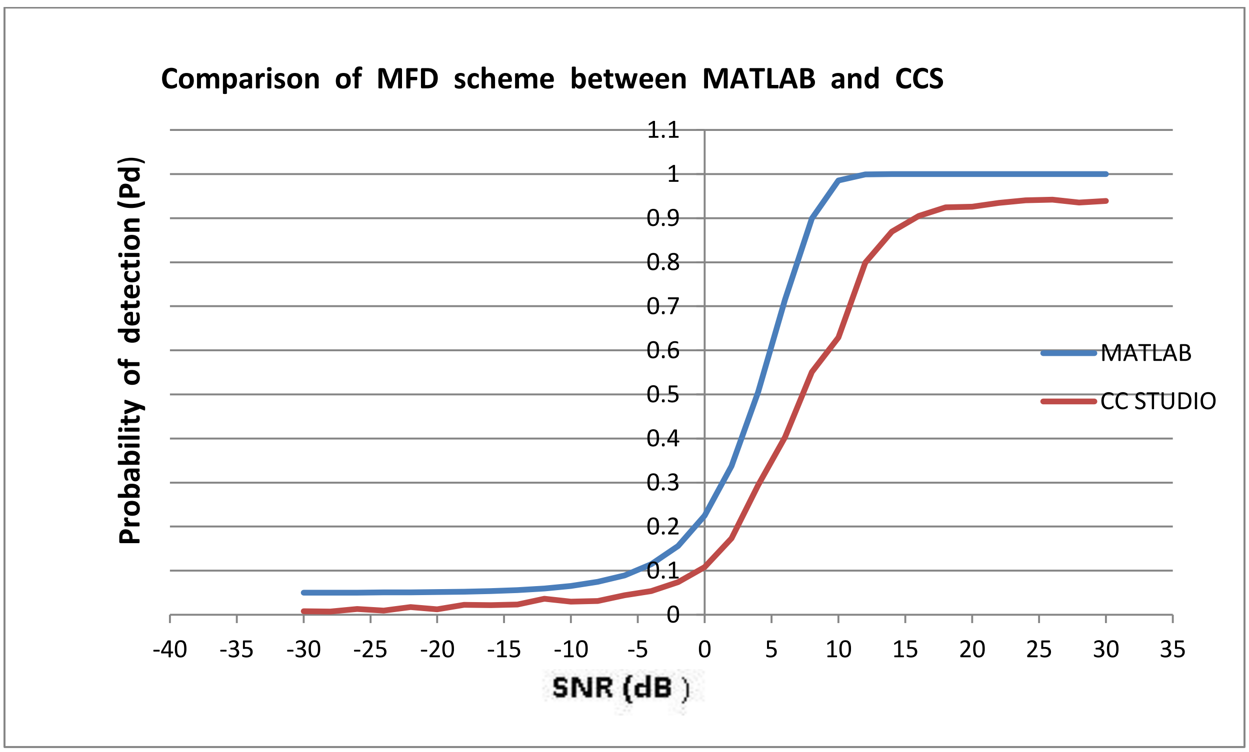


Fig. 5.5. Pd vs SNR for CFD scheme

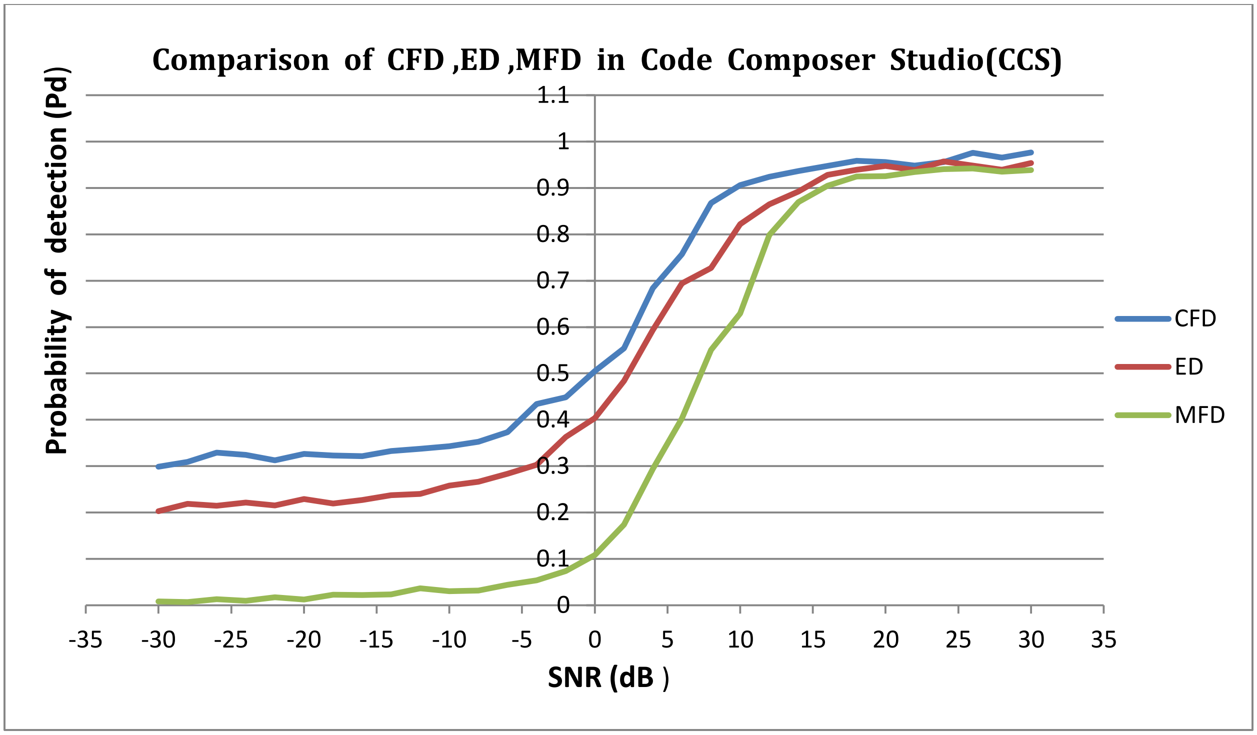


Fig. 5.6. Pd vs SNR for comparison of ED,CFD, MFD scheme

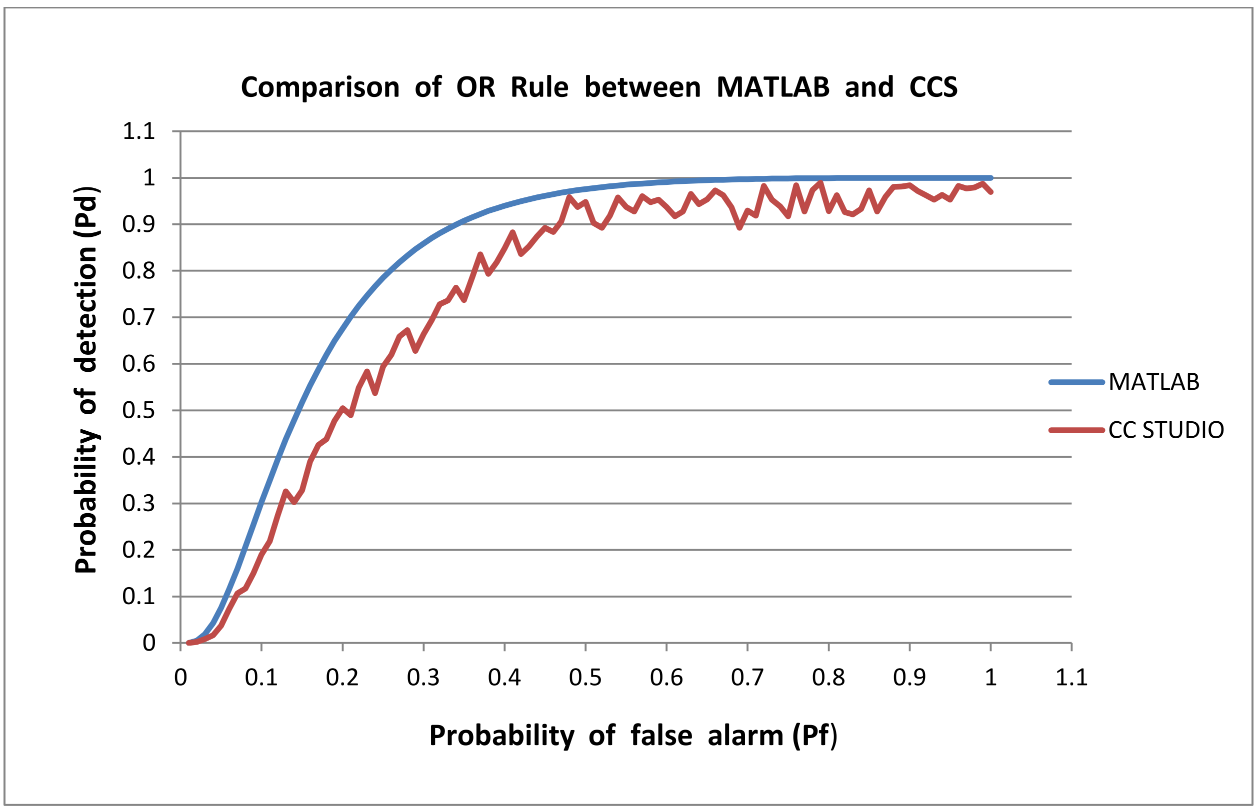


Fig. 5.7. Pf vs Pd for OR rule under Hard decision fusion scheme

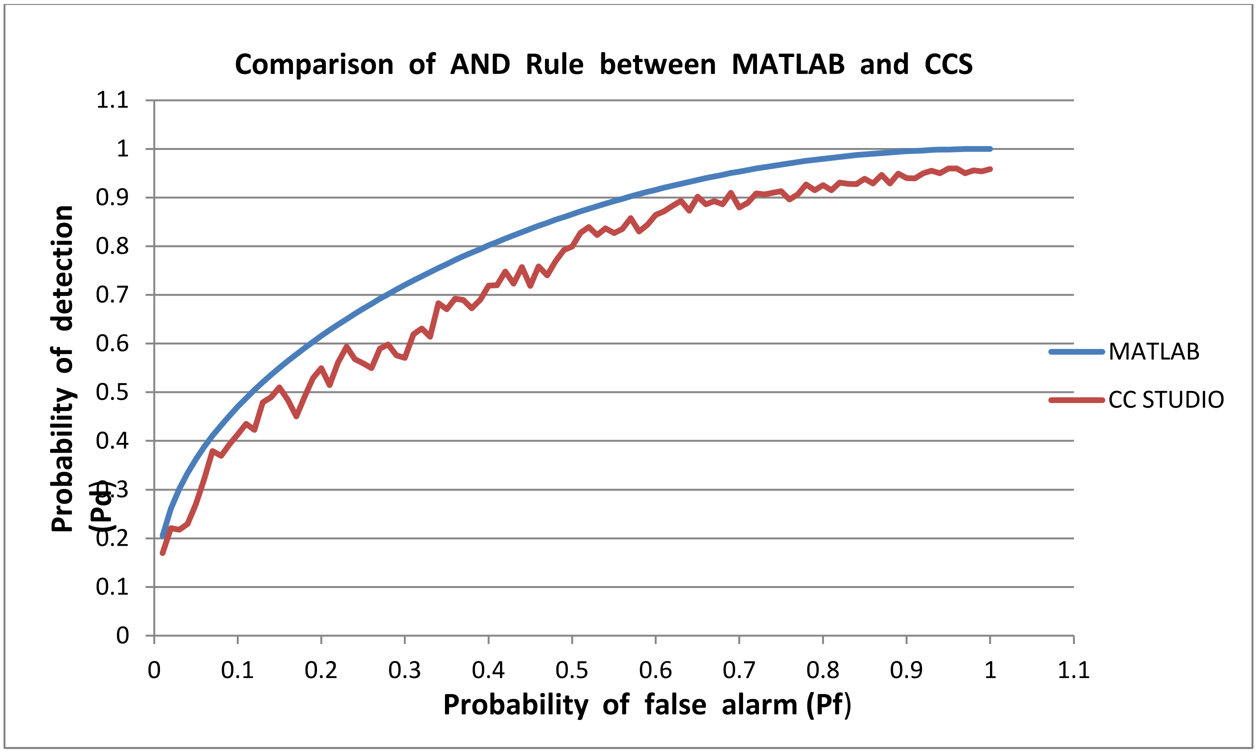


Fig. 5.8. Pf vs Pd for AND rule under Hard decision fusion scheme

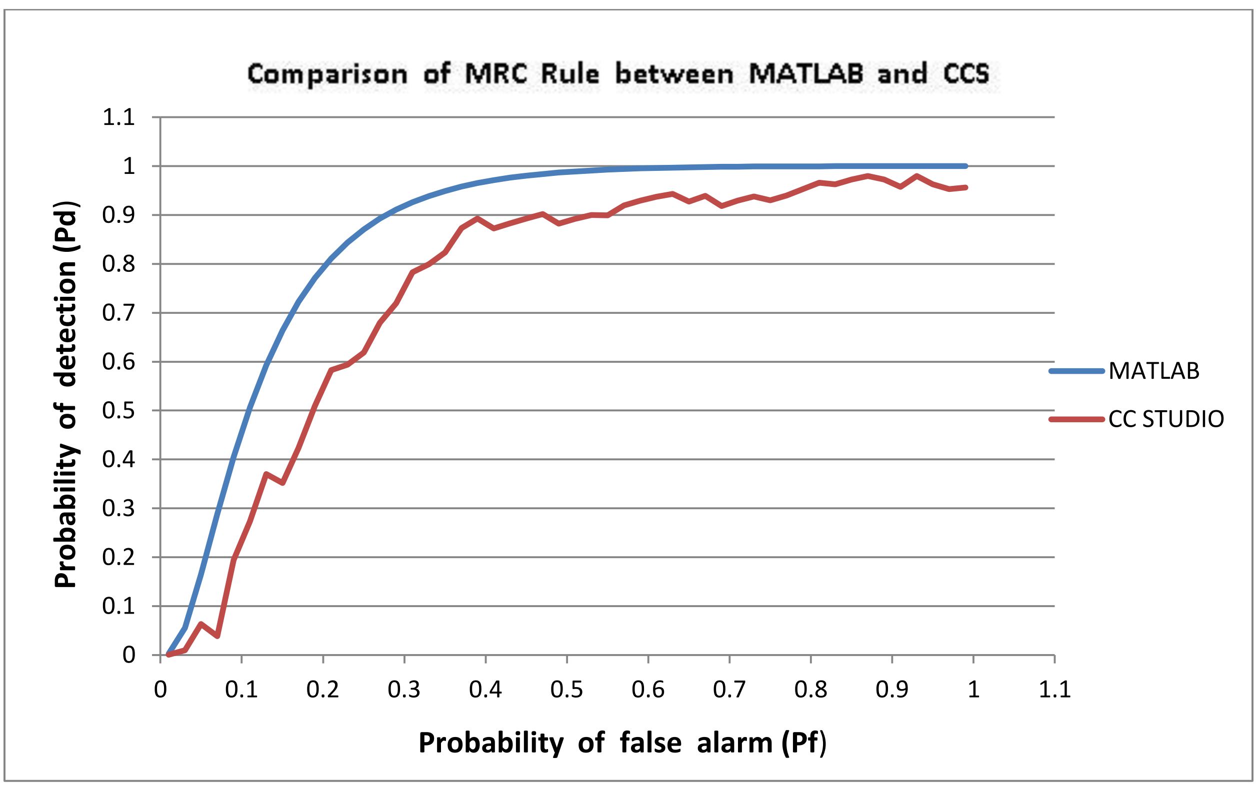


Fig. 5.9. Pf vs Pd for MRC rule under Soft decision fusion scheme

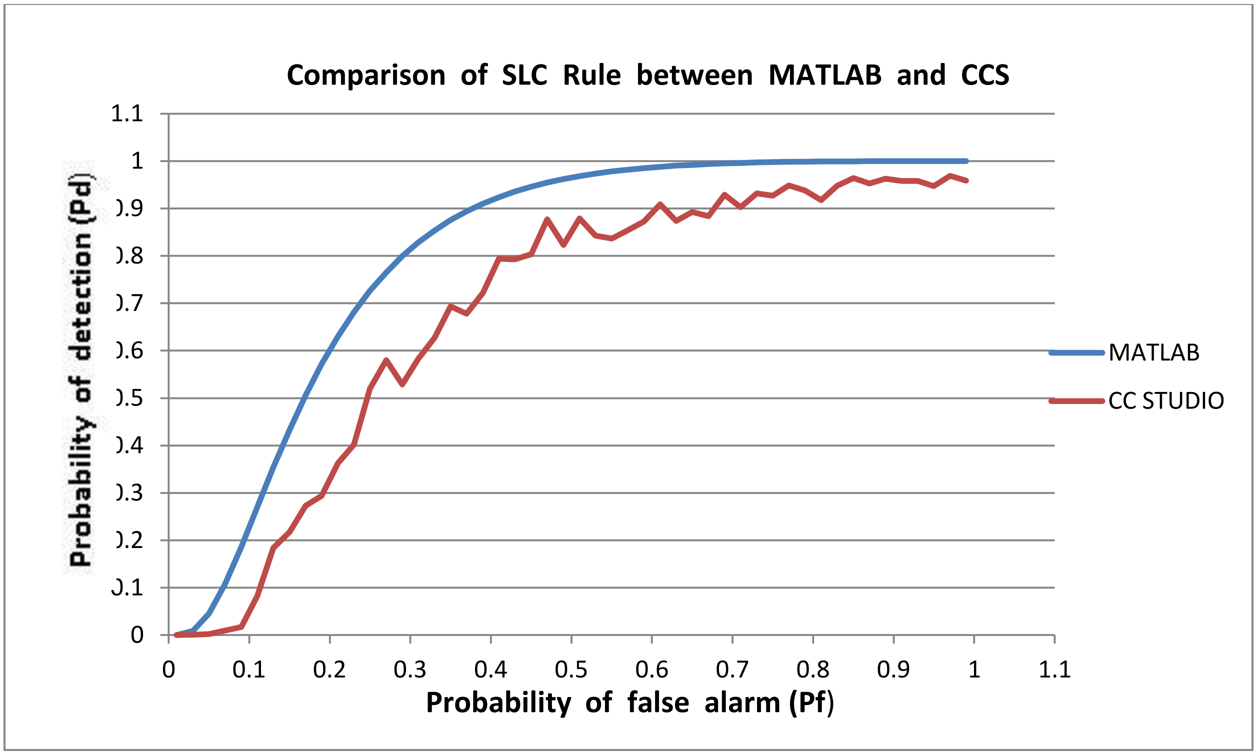


Fig. 5.10. Pf vs Pd for SLC rule under Soft decision fusion scheme

From the figure 5.3 to 5.5 it is observed that the ROC curve is approximately same for MATLAB and CCS with a little performance reduction in CCS than MATLAB.we can also observe from Fig.5.6 that CFD has better performance than ED and MFD when compared each other in CCS platform. The performance gap between the results obtained from CCS and MATLAB is may be due to the use of hardware tools.

In the figure 5.7 to 5.10 logical OR, AND fromr Hard decision and SLC,MRC rule from Soft decision scheme has been implemented through MATLAB and CCS. It is found that results obtained from CCS are nearly same as that of obtained in MATLAB but with a small performance degradation which may be due to the use of hardware tools.

6

CONCLUSION

6.1 Conclusion :

Cognitive Radio is the exceptional innovation being used in modern wireless market. All the rising innovation is utilizing Cognitive Radio for its whole system. Likewise, every system need to manage the primitive interest of spectrum sensing in Cognitive Radio. There are various strategies, which have been actualized to check the spectrum band occupancy details of the underused frequency spectrum bands of the licensed users. Three simple and basic transmitter detection schemes with their pros and cons and performance has been studied and compared in this thesis.

The static frequency assigning policy is the key problem for spectrum usage, which brings about spectrum deficiency. The idea of CR deals with this trouble up to some degree. The spectrum sensing schemes has been examined and it is observed that the CFD method outperforms the ED and MFD schemes..

Due to some major spectrum detection problems which includes fading, receiver uncertainty and shadowing, Cooperative sensing is proposed to eradicate these problems. The key idea of this detection scheme is to enhance the sensing performance by taking the advantage of spatial diversity. Hard decision and soft decision schemes with some combination rules are discussed such as AND,OR under hard decision and SLC,MRC under soft decision. It has been observed from the simulation curves that logical OR rule performs better than logical AND rule under hard decision and MRC outperforms SLC rule under soft decision techniques. Comparison between hard and soft decision rule has also been carried out by taking the curves for AND rule and SLC rule and finally it is observed that soft decision scheme has an edge over the hard one. Number of CRs in the cooperation process are also varied and the results are compared, then its observed that as the number of CR users increases the sensing performance goes better .

All the spectrum sensing techniques discussed above are implemented in hardware platform by using TMS320c6713DSK which is a DSP microprocessor. This DSP kit is programmed through Code Composer Studio(CCS) which supports C/C++ language for all the sensing schemes explained before. Due to the problem in graph plotting between two array in CCS , the values of the arrays are taken and plotted in Microsoft Excel. Also the values are taken from the workspace of MATLAB for that arrays and comparison is done between the MATLAB and CCS results. It is observed that MATLAB has better result than the CCS results but with a small difference which may be due to many factors associated with hardware but that is not a problem in MATLAB which is a software tool.

6.2- Future Scope & Limitations:

Theoretical analysis with mathematical derivation has been done in this thesis. For simulation, assumptions were made for the licensed user signal that the random bit stream is transformed into a Binary PSK signal, and the simulation study having considered the real radio spectrum data or around the real environment were not attempted.

Monte Carlo simulation validity for real spectrum environment will further improve the application of the proposed technology. Many other DSP kits can be employed for spectrum sensing purpose of all the schemes discussed above and their results can be compared to the existing simulation results.

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Online Resources:

1. www.wikipedia.org
2. www.google.com – Search Engine for data and images